# FDS ANALYSIS OF THE EFFECT OF 4-WAY CEILING AIR DIFFUSERS ON QUICK RESPONSE SPRINKLER ACTIVATION TIME

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# ABSTRACT

NFPA 72, *The National Fire Alarm Code*, addresses the increase in smoke detector activation time due to close proximity to air diffusers. NFPA 13, *Installation of Sprinkler Systems*, does not address the effect of horizontal ceiling air velocity on sprinkler activation time in commercial buildings. A Fire Dynamics Simulator (FDS) analysis was conducted to examine the effects of higher air velocities from air conditioning systems on sprinkler activation time.

A light hazard occupancy office space was selected for analysis. The dimensions of the office space are 3.7 m x 3.7 m x 2.4 m tall (approximately 12 ft x 12 ft x 8 ft tall). A quick response sprinkler was placed in the center of the room.

The results of the study show that a ceiling level air diffuser placed 0.6 m (2 ft) or less from a quick response sprinkler has detrimental effect on activation time. The study did also show that activation time delay did not necessarily increase as the diffuser was moved closer to the QR sprinkler. When quick response sprinklers are installed in high air movement areas, mission critical spaces, or high value storage areas, consideration should be given to the detrimental effect of high velocity ceiling diffuser on QR sprinkler activation time.

## INTRODUCTION

NFPA 72, *The National Fire Alarm Code*, addresses the increase in smoke detector activation time due to close proximity to air diffusers. Section A.5.7.4.1 of NFPA 72 (2007) states that smoke detectors should not be located closer than 1 m (3 ft) from an air supply diffuser. The purpose of this prescriptive spacing limitation is to minimize the impact of downward air from a heating, venting, and air-conditioning (HVAC) system on smoke movement toward the smoke detector.

NFPA 13, *Installation of Sprinkler Systems*, does not currently address the effect of horizontal ceiling air velocity on sprinkler activation time in commercial buildings. Section 8.1.1 of NFPA 13 does state that "sprinklers shall be positioned and located so as to provide satisfactory performance with respect to activation time and distribution."

A Fire Dynamics Simulator (FDS) analysis was conducted to examine the effects of higher air velocities from air conditioning systems on sprinkler activation time.

This study was inspired by the NFSA Report: Interaction of Residential Sprinklers, Ceiling Fans and Similar Obstructions, by Victoria Valentine, P.E. and Kenneth Isman, P.E. The NFSA study examined the effects on sprinkler activation time and water distribution due to proximity to ceiling fans.

## METHODOLOGY

A common commercial office occupancy was chosen as the model space in order to examine the effects of airflow from a ceiling diffuser on sprinkler activation time. A quick response sprinkler was placed in the center of the room.

The following modeling plan was implemented:

1. Select typical air diffuser to place in room between fire and QR sprinkler. The Titus TDC-AA 4-Way Air Diffuser was chosen.
2. Develop FDS model of air diffuser to match expected velocities from data sheet.
3. Model activation time for a quick response sprinkler in the office model without an air diffuser for the following base fires:
    1. a workstation fire,
    2. ultrafast-growth fire,
    3. fast-growth fire,
    4. medium-growth fire,
    5. slow-growth fire, and
    6. a trash can fire
4. Compare base fire models from FDS to DETACT-T2 results for sprinkler activation time.

5. Add the air diffuser at 0.6 m, 0.3 m, and 0.2 m (2 ft, 1 ft, and ½ ft) from sprinkler in the FDS models and examine affect on QR sprinkler activation time.
6. Re-perform base model with standard response sprinklers without air diffuser for all scenarios.

LIMITATIONS

This study has the following limitations:

1. No fire testing was performed. Analysis was performed only with computer modeling.
2. Water application was not examined; only activation time was examined.
3. The location of the sprinkler in the office was held constant in all the FDS models.
4. One commercial space (an office) was examined. Other commercial applications were not examined.
5. One velocity profile for the air diffuser was modeled. The velocity profile was chosen after consultation with two mechanical engineers. The velocity profile chosen reflects a common installation and velocity profile design for a commercial office space.

MODEL DESCRIPTION

Office Space

A light hazard occupancy office space was selected for this analysis. The dimensions of the office space are 3.7 m x 3.7 m x 2.4 m tall (approximately 12 ft x 12 ft x 8 ft tall) (See Figure 1).

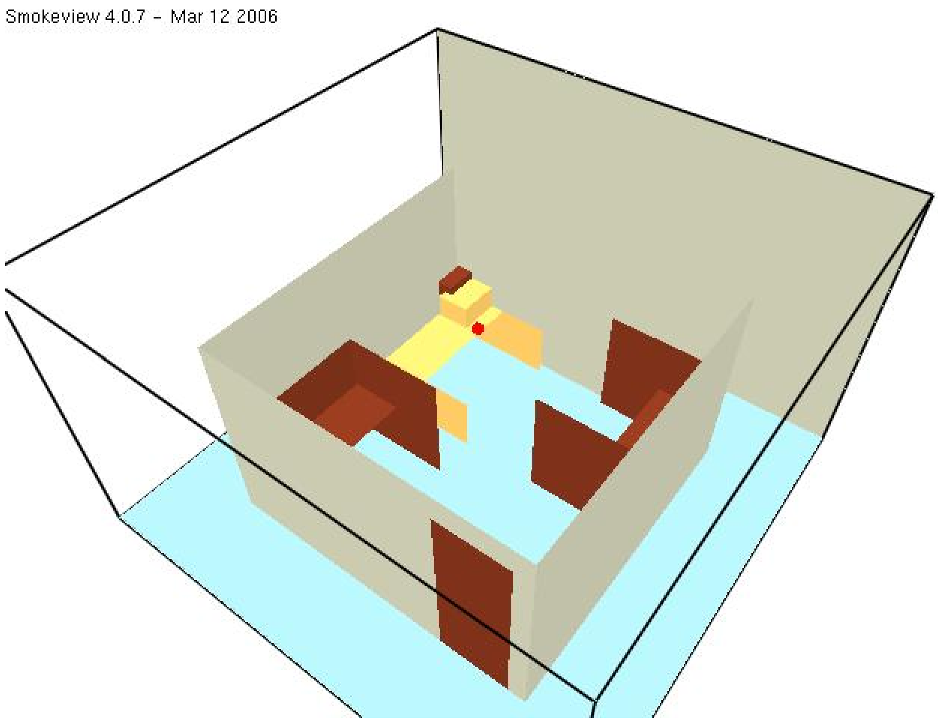



*Figure 1: Office Model*

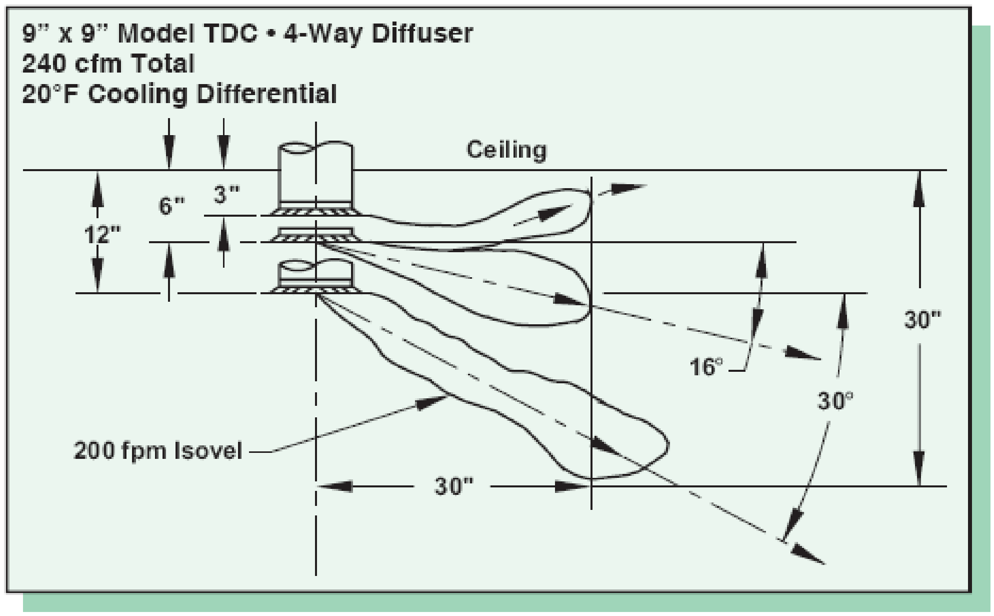
The FDS models incorporated the following features:

- The floor is carpeted.
- The walls are constructed of gypsum board.
- The ceiling is mineral-based ceiling tile.
- The door to the office is closed.
- The workstations are 1.2 m x 1.5 m x 1.1 m tall (4 ft x 5 ft x 3.6 ft tall) spruce wood workstations
- A sprinkler was provided at the center of room 0.1 m (approximately 4 in) from the ceiling.
- Quick response sprinkler has the following features: fusible element rated for 68°C (155°F); RTI = 50 $(m\text{-}sec)^{1/2}$
- Standard response sprinkler has the following features: fusible element rated for 68°C (155°F); RTI = 177 $(m\text{-}sec)^{1/2}$

<u>Air Diffuser</u>

A commonly specified air diffuser to place in the model was desired. The Titus TDC-AA 4-Way Air Diffuser was chosen.

Figure 2 shows the recommended maximum airflows in cubic feet per minute (cfm) for various ceiling heights.




**Recommended Maximum Airflow**

| Ceiling Height, ft. | 8 | 9 | 10 | 12 | 15 | 20 |
|---|---|---|---|---|---|---|
| Airflow, cfm, per Side | 200 | 350 | 550 | 900 | 1500 | 4000 |

*Figure 2: Maximum Airflow for Titus Model TDC 4-Way Diffuser (From Product Data Sheet)*

For the 2.4 m (8 ft) tall office space, a maximum airflow of 0.1 $m^3$/sec (200 cfm) is specified per side.

From the Titus Data Sheet for the selected diffuser, a throw of 5-8-12 is specified for airflow of 0.1 $m^3$/sec (200 cfm). The throw of 5-8-12 means that at a distance of 1.5 m (5 ft), a terminal velocity of 0.8 m/s (150 fpm) is provided. At a distance of 2.4 m (8 ft), a terminal velocity of 0.5 m/s (100 fpm) is provided. At a distance of 3.7 m (12 ft), a terminal velocity of 0.3 m/s (50 fpm) is provided.

FDS provides a means to inject air into a model space. FDS also provides a means to increase or decrease the tangential velocity of the airflow into the model. However, the velocity profile could not be made within FDS to resemble the velocity profile of an actual ceiling level air diffuser. The actual air diffuser should have 100% of its velocity travel along the ceiling with no downward velocity. Adjusting the air velocity in FDS with the tangential velocity prescription would still result in a downward velocity of airflow.

The solution was to prescribe a downward airflow into the model and insert an inert plate 0.1 m (4 in) below the vent. The airflow would strike the inert plate and radiate outward at the velocities specified by Titus. The inert plate extended 0.1 m (4 in) horizontally from the sides of the vent into the office (See Figure 3).

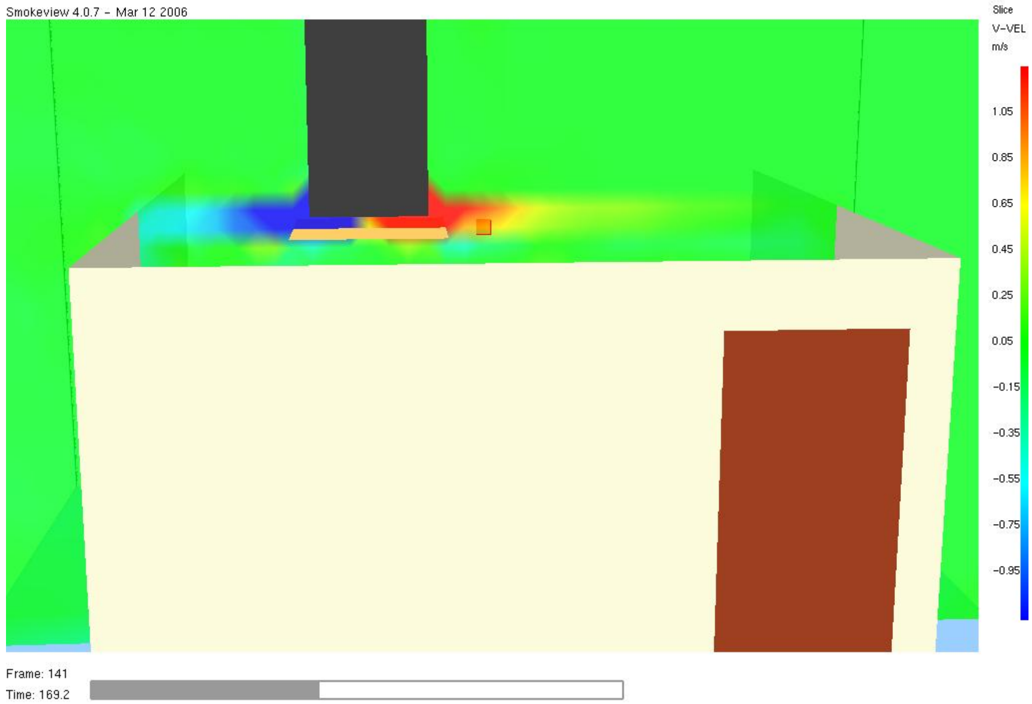



*Figure 3: Velocity Profile of Vent into Model with Inert Plate*

A velocity of 2.1 m/s (413 fpm) into the space with a tangential velocity of 2.1 m/s (413 fpm) in conjunction with the inert plate yielded a velocity profile which closely matched the velocity profile specified by Titus for this ceiling level air diffuser.

## FIRE SCENARIOS

### Workstation Fire

Figure 4 shows a heat release rate (HRR) curve for a 3-panel workstation.

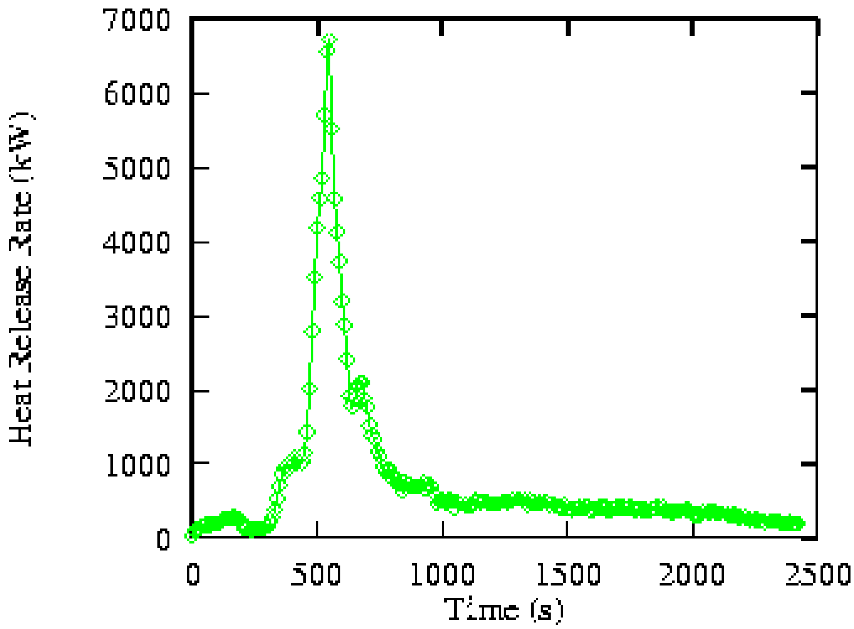



*Figure 4: HRR Curve for 3-Panel Workstation (Source: [www.fire.nist.gov](http://www.fire.nist.gov))*

In FDS, the activation time of the quick response sprinkler without the air diffuser is 348 seconds (See Figure 5).

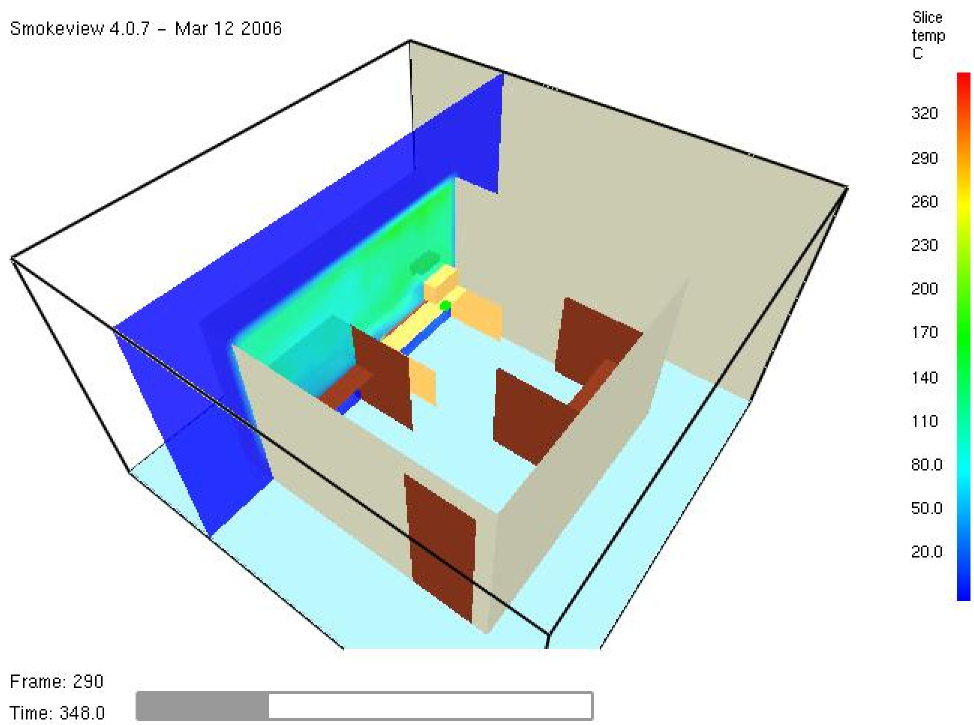



*Figure 5: Workstation Fire, Sprinkler Activation Time*

The HRR curve has 300 sec of smoldering. After 300 sec, the HRR curve acts as an ultrafast fire. The activation time predicted by DETACT-T2 is 48 sec + 300 sec = 348 sec.

The 4-way air diffuser was inserted into the FDS model at 0.6 m (2 ft), 0.3 m (1 ft), and 0.2 m (1/2 ft) away from the sprinkler. The diffuser was inserted between the fire and the sprinkler (See Figure 6).

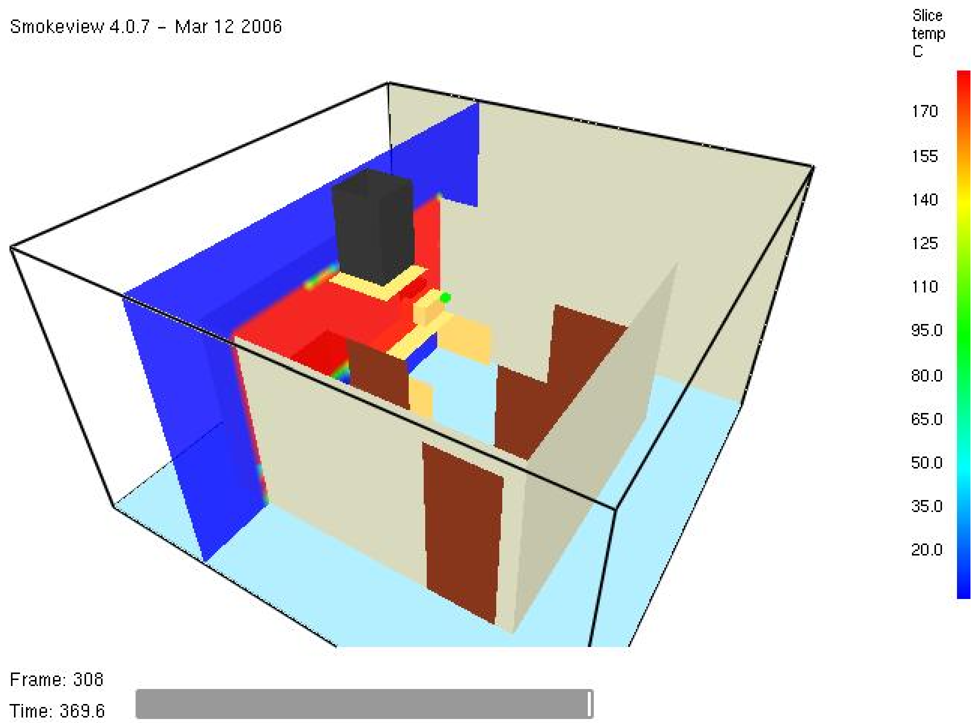



*Figure 6: Workstation Fire, Diffuser at 0.6 m (2 ft) from Sprinkler, Sprinkler Activation Time of 369 sec*

The following quick response sprinkler activation times ($t_{act}$) were modeled with FDS for the workstation fire scenarios:

$t_{act}$ (0.6 m (2 ft)) = 369 sec, % Increase in Activation Time = 6%
$t_{act}$ (0.3 m (1 ft)) = 394 sec, % Increase in Activation Time = 13%
$t_{act}$ (0.2 m (½ ft)) = 428 sec, % Increase in Activation Time = 23%

For comparison, the FDS model was performed on the base workstation fire without the air diffuser with a standard response sprinkler. The following sprinkler activation time was modeled with a standard response sprinkler in the workstation fire:

$t_{act}$ (SR) = 384 sec, % Increase in Activation Time = 10%

$t^2$ Growth Fires

An FDS analysis was also performed for the four traditional $t^2$ growth fires: slow, medium, fast and ultrafast fires. From Figure 6-22 from Principles of Fire Behavior, Dr. James G. Quintiere, Delmar Publishers, the $t^2$ growth fires are defined as fires with a HRR of 1 MW at the following times:

| | |
|---|---|
| slow growth | $t_1$ = 600 sec |
| medium growth | $t_1$ = 300 sec |
| fast growth | $t_1$ = 150 sec |
| ultrafast growth | $t_1$ = 75 sec |

The workstation fire was replaced the HRR curves of the four traditional $t^2$ growth fires.

The following sprinkler activation times were modeled in FDS for a slow growth fire:

$t_{act}$ (Base without Diffuser) = 199 sec
$t_{act}$ (DETACT-T2) = 193 sec
$t_{act}$ (0.6 m) = 378 sec, % Increase in Activation Time = 90%
$t_{act}$ (0.3 m) = 237 sec, % Increase in Activation Time = 19%
$t_{act}$ (0.2 m) = 384 sec, % Increase in Activation Time = 92%
$t_{act}$ (SR) = 255 sec, % Increase in Activation Time = 28%

The following sprinkler activation times were modeled in FDS for a medium growth fire:

$t_{act}$ (Base without Diffuser) = 126 sec
$t_{act}$ (DETACT-T2) = 117 sec
$t_{act}$ (0.6 m) = 180 sec, % Increase in Activation Time = 43%
$t_{act}$ (0.3 m) = 166 sec, % Increase in Activation Time = 32%
$t_{act}$ (0.2 m) = 187 sec, % Increase in Activation Time = 48%
$t_{act}$ (SR) = 162 sec, % Increase in Activation Time = 28%

The following sprinkler activation times were modeled in FDS for a fast growth fire:

$t_{act}$ (Base without Diffuser) = 74 sec
$t_{act}$ (DETACT-T2) = 74 sec
$t_{act}$ (0.6 m) = 103 sec, % Increase in Activation Time = 39%
$t_{act}$ (0.3 m) = 84 sec, % Increase in Activation Time = 14%
$t_{act}$ (0.2 m) = 100 sec, % Increase in Activation Time = 35%
$t_{act}$ (SR) = 98 sec, % Increase in Activation Time = 32%

The following sprinkler activation times were modeled in FDS for an ultrafast growth fire:

$t_{act}$ (Base without Diffuser) = 48 sec
$t_{act}$ (DETACT-T2) = 48 sec

$t_{act}$ (0.6 m) = 63 sec, % Increase in Activation Time = 31%
$t_{act}$ (0.3 m) = 63 sec, % Increase in Activation Time = 31%
$t_{act}$ (0.2 m) = 58 sec, % Increase in Activation Time = 21%
$t_{act}$ (SR) = 63 sec, % Increase in Activation Time = 31%

Trash Can Fire

In the same office space, a small trash can fire was modeled. From A Sprinkler Fire Suppression Algorithm for the GSA Engineering Fire Assessment System, D. Madrzykowksi and R. Vettori, NISTR 4833, a trash can fire can be represented by a gas burner operated at 50 kW for 200 sec.

A 1 $m^2$ area vent with an assigned heat flux value of 50 $kW/m^2$ was inserted into the model as the trash can fire source.

A base quick response sprinkler activation time without diffuser of 101 sec was modeled.

There was no DETACT-T2 validation since this fire is a steady-state fire.

The air diffuser was added at a distance of 0.6 m from the sprinkler. The quick response sprinkler never actuated in the FDS model with the air diffuser placed 0.6 m from the sprinkler. The fire was terminated at 200 sec to model the fuel being consumed.

Table 1 shows the collected results from this study:

| MODEL | Workstation Fire | Slow Growth Fire | Medium Growth Fire | Fast Growth Fire | Ultrafast Growth Fire | Trash Can Fire |
|---|---|---|---|---|---|---|
| $t_{act}$ (Base) | 348 sec | 199 sec | 126 sec | 74 sec | 48 sec | 101 sec |
| $t_{act}$ (DETACT) | 348 sec | 193 sec | 117 sec | 74 sec | 48 sec | N/A |
| $t_{act}$ (0.6 m) | 369 sec | 378 sec | 180 sec | 103 sec | 63 sec | No AS Actuation |
| % Incr. (0.6 m) | 6% | 90% | 43% | 39% | 31% | No AS Actuation |
| $t_{act}$ (0.3 m) | 394 sec | 237 sec | 166 sec | 84 sec | 63 sec | N/A |
| % Incr. (0.3 m) | 13% | 19% | 32% | 14% | 31% | N/A |
| $t_{act}$ (0.2 m) | 428 sec | 384 sec | 187 sec | 100 sec | 58 sec | N/A |
| % Incr. (0.2 m) | 23% | 92% | 48% | 35% | 21% | N/A |
| $t_{act}$ (SR AS) | 384 sec | 255 sec | 162 sec | 98 sec | 63 sec | N/A |
| % Incr. (SR AS) | 10% | 28% | 28% | 32% | 31% | N/A |

*Table 1: Collected Results*

## OBSERVATIONS

The following observations were made from this study:

- A ceiling level air diffuser placed 0.6 m (2 ft) or less from a quick response sprinkler has a detrimental effect on sprinkler activation time.
- The activation time delay did not necessarily increase as the diffuser was moved closer to the QR sprinkler.

## RECOMMENDATIONS

When quick response sprinklers are installed in high air movement areas, mission critical spaces, or high value storage areas, consideration should be given to the detrimental effect on quick response sprinkler activation time due to proximity to ceiling air diffusers. The following actions by the sprinkler designer may be considered:

- Perform an FDS analysis to optimize QR sprinkler placement with ceiling level air diffuser location.
- Increase design area similar to that for dry-pipe sprinkler systems to compensate for >HRR at time of sprinkler activation.
- Consider installation of below floor HVAC.

## CONCLUSIONS

The results of the study show that a ceiling level air diffuser placed 0.6 m (2 ft) or less from a quick response sprinkler has detrimental effect on sprinkler activation time. The study did also show that activation time delay did not necessarily increase as the diffuser was moved closer to the QR sprinkler. When quick response sprinklers are installed in high air movement areas, mission critical spaces, or high value storage areas, consideration should be given to the detrimental effect of high velocity ceiling diffusers on QR sprinkler activation time.